Met.O.751

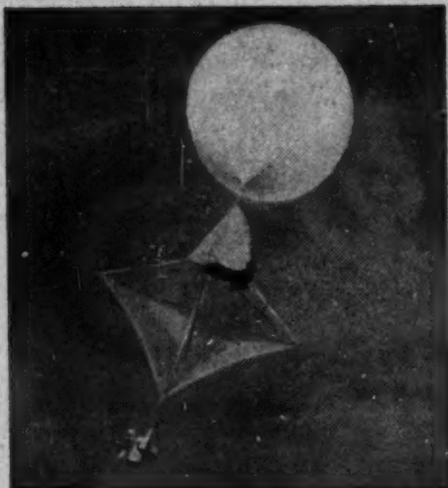
METEOROLOGICAL OFFICE

the meteorological magazine

For Mrs CB East.

DECEMBER 1964 No 1109 Vol 93

Her Majesty's Stationery Office



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THE METEOROLOGICAL MAGAZINE

Vol. 93, No. 1109, December 1964

551.509.314:551.509.324.2:551.578.4

A COMPARISON OF SNOW PREDICTORS

By C. J. BOYDEN

Summary.—Whether precipitation is likely to be in the form of rain or snow is normally determined by means of an index of atmospheric temperature. Six such predictors are examined, some discussion being included on how precipitation changes the magnitude of the predictor itself. On the assumption that the magnitude is accurately forecast, an assessment is made of the success of each predictor. The best are found to be (i) the height of the freezing-level and (ii) the 1000–850 mb thickness combined with the sea-level pressure.

Introduction.—In general the methods used in forecasting weather depend on how far in advance the forecast is required. Forecasting for the next day is dominated by broad-scale considerations, but for a few hours ahead there is greater emphasis on current trends. A predictor which is not very closely related to whether precipitation will be in the form of rain or snow is acceptable in the longer-period forecast. A more sensitive predictor is desirable when the forecast period is short enough for the predictor itself to be forecast with fair precision.

At British stations the decision as to whether rain or snow is the more likely is commonly based on the forecast 1000–500 mb thickness, which was investigated by Murray[1,2] and Lamb.[3] This is a crude predictor because the form of precipitation is determined by the lowest levels of the atmosphere and at least nine-tenths of the layer up to 500 mb has little or no bearing on the problem. As was pointed out by Murray, the justification for using such a deep layer is that the 1000–500 mb thickness is a standard parameter in synoptic analysis. Its success as a snow predictor is due to the degree of consistency, during precipitation, of the temperature lapse rates in the lower half of the troposphere. Because of this the temperature of the lowest layer, on which the thawing of snow-flakes depends, is moderately well indicated by the mean temperature of a much deeper layer.

It is obvious that the thickness of a shallower layer must be a more precise predictor. The 1000–700 mb layer, for example, excludes nearly half the irrelevant part included in the 1000–500 mb layer. It appears to be the less widely used of the two simply because the drawing of a 1000–700 mb chart may not be justified by other forecasting commitments.

The 1000–850 mb thickness is still better as a predictor of the form of precipitation because the melting layer extends through as much as one-quarter of its

depth. Mineeva[4] has studied the relationships between the critical stage for snow, the 1000–850 mb thickness and the temperatures near the ground and at the 850 mb level.

Murray[1,2] and Heissat[5] are among those who have also related the form of precipitation to the height of the freezing-level as well as to the screen temperature.

The purpose of the present paper is to compare the success of six predictors of the form of precipitation. To a large extent this success is evaluated on the assumption that the magnitude of the predictor at the time of the precipitation is known; how easily each predictor can be forecast has not been studied. Some discussion is included, however, on the interdependence of the predictors and the extent to which the magnitude of the predictor is controlled by the precipitation.

Observations used.—The investigation was based on observations made during the four winters 1955–56, 1957–58, 1961–62 and 1962–63, when snow fell more frequently than usual over the British Isles. The months used were December to March and all observations came from the radiosonde stations at Lerwick, Stornoway, Shanwell, Long Kesh, Aughton, Hemsby, Crawley and Camborne. Every 0000 GMT and 1200 GMT observation was extracted provided there was precipitation at the time the radiosonde was launched. (The observation times were 0300 GMT and 1500 GMT in the 1955–56 winter).

The few observations of ice pellets were excluded from the analysis because the definition of the associated code figures for present weather is not specific enough for our purpose. The total number of observations remaining was 1406, of which 1030 were made during rain, 300 during snow, and 76 during sleet (a mixture of rain and snow). No distinction was made in the analysis between showery and non-showery types.

Most of the analysis was carried out for each station separately, midnight and midday observations also being kept apart. This showed that for most purposes it was satisfactory to treat all observations collectively. Climatic differences between the north and south of the British Isles in winter did not seem to justify modifications in relationships intended to be used by forecasters. Variations in the elevation of stations above sea level were likewise not a serious complication since, with the exception of Crawley at 144 m, all are within 90 m of sea level.

The melting of falling snow.—Above the freezing-level (meaning the level of the 0°C isotherm, a term preferred by some writers) a cloud is likely to consist of supercooled water drops as well as ice crystals. This suggests that when precipitation is falling through the freezing-level some of it may at times be in the form of rain. However, out of 170 occurrences of precipitation at the ground when the freezing-level was also at the ground, only 3 were reported as rain and 4 as sleet, the remaining 163 falls being of snow. Thus when the freezing-level is at any height above the ground it is reasonable to assume that virtually all the precipitation originating above the freezing-level and reaching the ground as rain was initially in the form of snow. The part of the atmosphere below the freezing-level determines whether there will be rain or snow at the ground. The part above the freezing-level determines the number, size and structure of the snow-flakes falling through the freezing-level; these are characteristics which do not appear to be relevant to the forecasting of the form of precipitation at the ground.

The heat required to warm a snow-flake as it falls into a warmer environment is very small relative to the heat transfer which takes place during melting, evaporation and condensation, and can be neglected in thermodynamical considerations.

Each snow-flake may be regarded as a wet-bulb thermometer of irregular shape, falling at a speed which Langleben[8] has shown to be largely independent of its size, at least until melting is nearly complete. Melting cannot begin before the temperature of the surface of the snow-flake exceeds 0°C, that is to say before the wet-bulb temperature of the surrounding air exceeds 0°C. When precipitation begins the snow-flakes may fall through air with a comparatively low relative humidity, in which case melting does not begin at the freezing-level but at some distance below it. Below the freezing-level but above the melting layer the air is cooled by evaporation from snow-flakes and the freezing-level descends until, if saturation is reached, it coincides with the original 0°C wet-bulb isotherm.

Nevertheless, this distinction between dry-bulb and wet-bulb temperatures is rarely an important one in relation to the melting of snow except in showers which are too short-lived to have much effect on an initially low relative humidity. On these occasions the showers may be of snow even when dry-bulb temperatures are such that rain seems the more likely. The conclusion that humidity is usually unimportant is based on a comparison made between the degrees of saturation before and during precipitation. It was not possible to ascertain the changes in a moving parcel of air, so the following method was adopted. Using routine upper air soundings the depression of the dew-point below the dry-bulb temperature, both at the 850 mb level and at the ground, was noted during precipitation. These figures were compared with the readings 12 hours earlier at the same station, provided there was no precipitation at that time. Selection of the occasions was made in this way to exclude most of the highly subsided air through which precipitation was unlikely to fall for a long time. The comparisons were made for Long Kesh and Hemsby and there was close agreement between the two stations, the median dew-point depression decreasing from 3.2°C to 1.0°C at 850 mb and from 1.7°C to 0.7°C at the surface. This decrease in dew-point depression was due not only to evaporational cooling but also to the cooling by the melting of snow and often to the arrival of air with a higher relative humidity. If evaporational cooling is taken to be the sole cause it can be assumed that the wet-bulb temperature was unchanged. The corresponding decrease in dry-bulb temperature would average about 0.7°C, the equivalent decrease in 1000–850 mb thickness being 3–4 metres. If the comparison could be made over a shorter period than 12 hours there is little doubt these figures would be smaller. In considering the probability that snow will melt it is therefore justifiable for the forecaster to examine dry-bulb temperatures without regard to humidity, as well as to ignore the effect of evaporational cooling on the 1000–850 mb thickness and probably on the height of the freezing-level.

Temperature changes caused by the melting of falling snow.—The temperature structure of the melting layer and the underlying atmosphere was first noted by Findeisen.[7] Melting of the snow begins just below the freezing-level and is completed within about 300 metres of it. The latent heat of fusion is abstracted from this layer, which therefore cools towards 0°C. The cooling

induces instability in the underlying air, an adiabatic lapse rate therefore progressively spreading downwards in it. As the melting layer becomes colder it is less effective in melting snow-flakes, so as time goes on the snow is able to fall to a lower level before being completely melted. Thus both the melting layer and the unstable layer below it move slowly down through the atmosphere while precipitation continues. If the base of the melting layer reaches the ground the rain there turns to sleet and then to snow, but this stage is not commonly reached because of the advection of warmer air possessing a higher freezing-level.

A fairly reliable estimate of the temperature structure from the freezing-level to the ground can be made by considering the variation of mean lapse rate with the height of the freezing-level. Figure 1 shows this relationship, the mean lapse rate (°C/mb) being the surface temperature divided by the pressure difference between the ground and the freezing-level. The curve shows a moderate lapse rate when the freezing-level is high and an increasing lapse rate with lowering freezing-level until this is about 50 mb above the ground. Below this level there is a fairly rapid decrease in lapse rate with decreasing height.

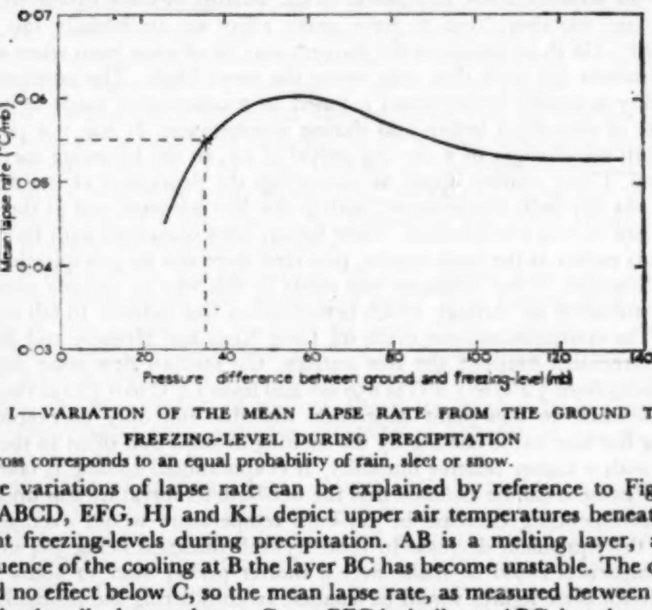

FIGURE 1—VARIATION OF THE MEAN LAPSE RATE FROM THE GROUND TO THE FREEZING-LEVEL DURING PRECIPITATION

The cross corresponds to an equal probability of rain, sleet or snow.

These variations of lapse rate can be explained by reference to Figure 2, where ABCD, EFG, HJ and KL depict upper air temperatures beneath four different freezing-levels during precipitation. AB is a melting layer, and in consequence of the cooling at B the layer BC has become unstable. The cooling has had no effect below C, so the mean lapse rate, as measured between A and D, can be described as moderate. Curve EFG is similar to ABC, but the unstable layer has reached the ground, so the lapse rate between E and G is relatively high. HJ represents the situation in which the melting layer just extends to the ground, giving an equal probability of rain, sleet or snow. The mean lapse rate in HJ is markedly less than in EG because there is no unstable layer. Curve KL indicates only partial melting of each snow-flake and the precipitation at the ground would almost certainly be snow.

The lapse rate in a melting layer depends on the initial lapse rate and the amount of snow subsequently melted at each level. If the temperature at a particular level is well above freezing-point the melting is rapid and so therefore is the

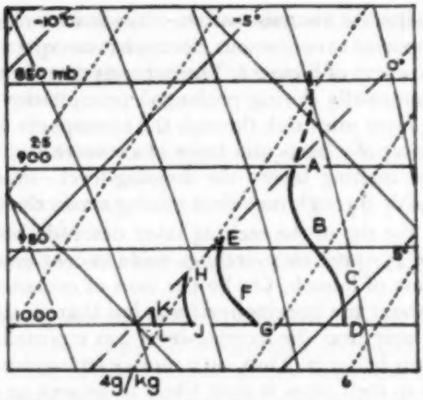

FIGURE 2—THE TEMPERATURE PROFILES BELOW VARIOUS FREEZING-LEVELS

cooling of the air. As the air becomes colder its effectiveness in melting the snow is reduced, as also is its own rate of cooling. Thus a fair degree of uniformity is to be expected in the lapse rate of a melting layer whatever its height. Since the heat required to melt a given mass of snow involves the integrated product of the depth and positive temperature of the melting layer, a degree of uniformity would also be expected in the depth of the melting layer.

It was found that rain, sleet and snow occurred with equal frequency when the freezing-level was 35 mb above the ground, so this was taken as the mean depth of the melting layer. Figure 1 shows the corresponding mean lapse rate to be 0.055°C/mb which is close to saturation and gives a mean temperature difference of nearly 2°C between the base and top of the melting layer. When the freezing-level is so low that a complete melting layer does not exist, the lapse rate within it cannot easily be measured. In Figure 1 extrapolation of the curve to the left suggests the lapse rate is small in an incomplete melting layer. This implies that when there is a complete melting layer the lapse rate is likely to be smallest in its upper part (see Figure 2). This variation of lapse rate is to be expected since, because the melting layer sinks during precipitation, the upper part of the layer has been a thawing agent for longer than the lower part. Moreover, there is a turbulent upward transfer of heat to the base of the melting layer.

That there is a fair degree of uniformity in the depths and lapse rates of melting layers was also shown by an analysis of occasions when sleet was falling. This form of precipitation indicates that there is an almost complete melting layer with its base at the ground. The freezing-level heights showed a pronounced mode between 30 and 40 mb, and less than 20 per cent of melting layers were as deep as 50 mb. The corresponding uniformity of mean lapse rate was confirmed by 76 per cent of surface temperatures (reported in whole degrees Celsius) being either 1°C or 2°C. These temperatures were controlled to some extent by the snow cover on the ground but this could not have been a major factor since there was no comparable peak in the distribution of surface temperatures during rain or snow.

The lowering of the freezing-level in precipitation.—On general grounds one might expect that the greatest departure from a uniform depth and mean lapse rate of the melting layer would occur when the precipitation

was prolonged. A separate analysis was therefore made on occasions when the precipitation was reported as continuous. Somewhat unexpectedly the lapse rates fitted fairly well the curve of Figure 1. This suggests that the profiles of Figure 2 do not change substantially during prolonged precipitation. Nevertheless the base of the melting layer must sink through the atmosphere as cooling proceeds and the melting power of a particular layer of air decreases. The implication is that the top of the melting layer—the freezing-level—must descend correspondingly, presumably through turbulent mixing across the freezing-level.

To confirm that the top of the melting layer descends, an examination was made of a sample of 25 upper air soundings made in continuous rain which was moderate at the time of launch. On 80 per cent of occasions the mean lapse rate in the 40 mb above the freezing-level was less than in the 40 mb below it. Moreover a stable layer near the freezing-level was reported much more often just above it than just below it. Thus, on a routine tephigram, the evidence that heat has been used to melt snow is most likely to be seen as a relatively stable layer just above the freezing-level (the broken line above A in Figure 2). The active melting layer (AB) may be accompanied by too small a change of lapse rate to be mentioned in the upper air report.

On the assumption that during continuous rain at the ground the temperature lapse rate for some distance down from the freezing-level remains unchanged, an estimate can be made of the rate of lowering of the freezing-level in terms of the rate of rainfall. The temperature profiles for different air columns shown in Figure 2 may now be regarded as successive profiles in the same column of air through which precipitation is falling. Although there is some variation in the profiles (corresponding to lapse-rate variations in Figure 1), it may be assumed as a first approximation that the mean temperature change between two nearby curves is equal to the temperature change in the region just below the freezing-level.

Let p_g = pressure at the ground in mb,
p_f = pressure at the freezing-level in mb,
R = rainfall from the melting of snow-flakes in mm,
ΔT = mean temperature fall in °C in the layer from the freezing-level to the ground, caused by the melting of snow,
Δp_f = lowering of freezing-level accompanying the mean temperature fall ΔT.

Lumb[8] has shown that

$$R = 0.056 \ \Delta T \ (p_g - p_f). \qquad \ldots (1)$$

In the derivation of this result it was assumed that the air was saturated initially and allowance was made for the latent heat of condensation.

Taking 0.05°C/mb as the mean lapse rate, we may write $\Delta T \simeq 0.05 \ \Delta p_f$. Equation (1) then becomes

$$\Delta p_f \simeq \frac{360R}{p_g - p_f}. \qquad \ldots (2)$$

Thus for a rainfall rate of 1 mm/h a freezing-level about 50 mb above the ground lowers by about 7 mb/h. With a freezing-level 100 mb above the ground the rate of lowering is more than half this figure, perhaps 4–5 mb/h, since, as is seen from ABCD in Figure 2, the rate of cooling is more pronounced in the upper part of the layer. When the freezing-level is less than 50 mb above the ground its rate of descent is uncertain because of changes in lapse rate.

Snow predictors and their assessment.—The relative merits of the following predictors were investigated:

(i) Height of the freezing-level above the ground;
(ii) Screen temperature;
(iii) 1000–850 mb thickness;
(iv) 1000–850 mb thickness adjusted for sea-level pressure and station height;
(v) 1000–700 mb thickness;
(vi) 1000–500 mb thickness.

All these predictors are well known apart from (iv), which is presented for the first time.

No way of forecasting sleet appears to be known, though a few comments on this are given later in the paper. In computing the probabilities of snow an occurrence of sleet was therefore counted as half to snow and half to rain.

Sufficiently low values of any of these predictors give a 100 per cent probability of snow and when they exceed critical values it is certain that snow will not reach the ground. Apart from the difficulty of forecasting it, a predictor can be classified as a good predictor if it satisfies two requirements. The first is the obvious one that its magnitude should be associated with the expected form of precipitation on a high proportion of occasions. The second is that there should not be a wide range of values of the predictor in which one form of precipitation is not much more likely than the other.

The extent to which each predictor met the first requirement was found simply by establishing the critical value for which snow and rain were equally probable, and then adding together the number of occasions when rain occurred at a lower value and when snow occurred at a higher value. This is the number of failures shown in Table I.

TABLE I—NUMERICAL VALUES OF EACH PREDICTOR CORRESPONDING TO DIFFERENT PROBABILITIES OF SNOW, TOGETHER WITH UNCERTAINTY RATIOS AND NUMBERS OF TIMES THE PREDICTOR FAILED

Predictor	Mean level of predictor for given snow probability (*per cent*) 90	70	50	30	10	Uncertainty ratio (*per cent*)	Number of failures
Height of freezing-level above the ground (gpm)	12	25	35	45	61	9	54
Surface temperature (°C)	−0.3	1.2	1.6	2.3	3.9	11	62
1000–850 mb thickness (gpm)	1279	1287	1293	1297	1302	16	75
1000–850 mb thickness adjusted for sea-level pressure and station height (gpm)	1281	1290	1293	1298	1303	14	58
1000–700 mb thickness (gpm)	2751	2773	2789	2803	2823	20	100
1000–500 mb thickness (gpm)	5180	5238	5258	5292	5334	19	114

The extent to which the second, and less important, requirement was met was found by introducing a quantity which will be called the uncertainty ratio, defined as the percentage of all occurrences of precipitation for which the probability of snow lay between 25 per cent and 75 per cent, this choice of percentages being arbitrary. The uncertainty ratio of a predictor is an index which measures, for a given set of observations, the rapidity of a change from a high probability to a low probability of either form of precipitation. A low uncertainty ratio is a desirable feature of a predictor, but is by no means essential.

For all predictors, these figures, together with probability levels, are given in Table I.

(i) *Freezing-level as a snow predictor.*—The height of the freezing-level above the ground is the fundamental predictor of the form of precipitation. It is not therefore surprising that is shows the fewest forecasting failures of the six predictors, though by only a small margin. It also has the smallest uncertainty ratio. When the freezing-level fails to predict the right form of precipitation the probable cause is abnormality in the mean temperature of the layer between the ground and the freezing-level.

This predictor has the advantage that a rapid estimate can be made of the snow probability at a high level, since the height of the place (in mb) need only be subtracted from the estimated height of the freezing-level above sea level to give the appropriate value of the predictor. Possible causes of error are mentioned under predictor (iv).

In estimating the magnitude of this predictor allowance should be made for the lowering of the freezing-level caused by precipitation. It should be recognized that this is not a disadvantage of this predictor, but represents a refinement not possessed by the others.

On 3 per cent of occasions a second freezing-level was reported above the one used in the analysis. This appeared to have no significance in relation to the form of precipitation. (Freezing rain or drizzle was reported only once).

(ii) *Screen temperature as a snow predictor.*—Surface air temperature was an essential predictor of snow before regular upper air observations were made. It continues to be used because it is a quantity which is continuously measurable and because it is quite highly correlated with the form of precipitation. However, correlation alone does not justify the use of an element as a predictor.

There are several factors which make surface temperature in cold weather very difficult to forecast. It depends, for example, on cloud cover, whether the ground is frozen hard and whether there is a covering of snow. In addition the temperature falls fairly sharply as rain changes to snow, so extrapolated temperatures give little indication of when this is about to take place.

Figure 3 shows the mean relationships found between 1000–850 mb thickness and surface temperature for the three types of precipitation and for all of them together (full line). With a thickness of about 1290 geopotential metres, for example, snow occurs at a surface temperature on the average a little under 1°C and rain when the temperature is about 2°C higher. The form of precipitation could be no more than a consequence of temperature close to the ground but for the fact that the curve for combined precipitation forms is distorted in this region. This implies that it is the change of form which causes the temperature to be low for the thickness. The uneven curve for all precipitation implies that the frequency distributions of the thickness and temperature are dissimilar, temperatures of 3°C (where the curve is steep) being relatively infrequent and temperatures of 1–1.5°C more common. This corresponds to the surface temperature in Figure 2 falling more quickly from G to J than from J to L during a steady lowering of the freezing-level. Surface temperature must therefore be regarded as a particularly unreliable indicator of an impending change from rain to snow.

(iii) 1000–850 *mb thickness as a snow predictor.*—Figure 4 shows the mean relationship found between the 1000–850 mb thickness and the pressure at the

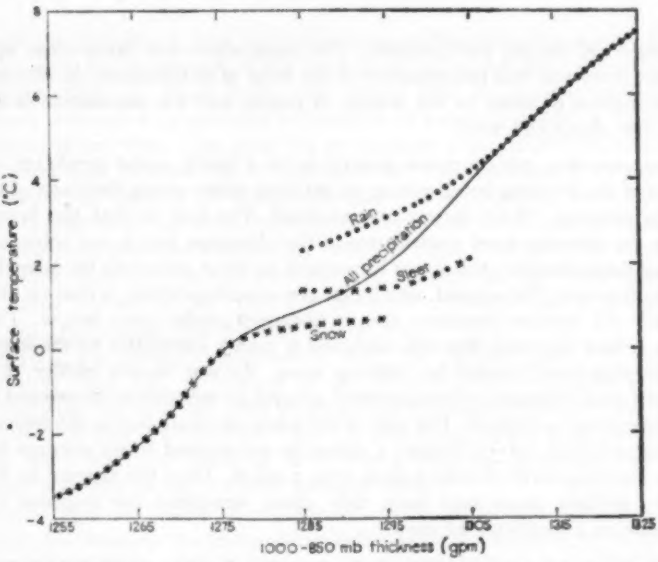

FIGURE 3—THE EFFECT OF THE FORM OF PRECIPITATION ON THE RELATIONSHIP BETWEEN SURFACE TEMPERATURE AND THE 1000–850 MB THICKNESS

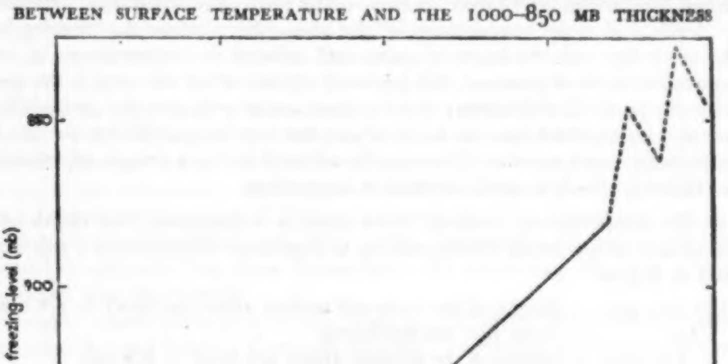

FIGURE 4—RELATIONSHIP BETWEEN THE 1000–850 MB THICKNESS AND THE PRESSURE AT THE FREEZING-LEVEL, BASED ON MEAN VALUES DURING PRECIPITATION

The broken line above 880 mb shows where the relationship becomes indefinite.
The cross shows where rain, sleet and snow are equally likely at the 1000 mb level.

freezing-level during precipitation. The association was fairly close up to the 880 mb level and was independent of the hour of observation. At 880 mb there was a sudden increase in the scatter of points and the association was a very loose one above this level.

The 1000–850 mb thickness proved to be a much worse predictor than the height of the freezing-level, giving 39 per cent more wrong forecasts of the form of precipitation. Three factors are involved. The first is that the layer of air above the freezing-level contributes to the thickness but is not relevant to the form of precipitation; this is not important on most occasions because this layer is a shallow one. The second, and by far the most important, is that no allowance is made for surface pressure; this is discussed under (iv), below. The third factor is that the 1000–850 mb thickness is rather insensitive to the lowering of the freezing-level caused by melting snow. As was shown earlier, a rainfall rate of 1 mm/h caused a freezing-level around 50 mb above the ground to lower at a rate of up to 7 mb/h. The rate of thickness decrease due to the melting snow is about 0.6 m/h, which Figure 4 shows to correspond to an average lowering of the freezing-level of only a little over 2 mb/h. Thus the change in thickness due to melting snow may have only about one-third the response which is desirable in a predictor of snow.

(iv) *Adjusted* 1000–850 *mb thickness as a snow predictor, allowance being made for sea-level pressure and height above sea level.*—The form of precipitation depends on the depth and mean temperature of the atmosphere below the freezing-level. The 1000–850 mb thickness is quite well related to temperatures at levels specified in units of pressure, but less well related when the unit is the height above sea level. The thickness alone cannot accurately give the probability of snow at a place which may be 200 m above the 1000 mb surface on one day and 200 m below it on another. This may be allowed for by a simple adjustment to the thickness which is easily applied in forecasting.

At the temperatures involved when snow is a possibility, the depth of the atmosphere at low levels corresponding to a pressure difference of 1 mb can be taken as 8 gpm.

Let z in gpm = height of the 1000 mb surface above sea level = $z/8$ mb,
Δz = 1000–850 mb thickness,
h in gpm = height of the ground above sea level = $h/8$ mb,
p_g = pressure at the ground in mb,
p_f = pressure at the freezing-level in mb,

then

$$p_g - p_f = (1000 + z/8 - h/8) - p_f \qquad \ldots (3)$$
$$= \mathrm{f}(\Delta z) + z/8 - h/8,$$

where the function $\mathrm{f}(\Delta z)$ is given by Figure 4.

In the important region where Δz is a little under 1300 gpm and the atmosphere may therefore be cold enough for snow, $\mathrm{f}(\Delta z)$ may be approximated to $3{\cdot}7\,(\Delta z - 1283)$, from measurement of the slope of the curve of Figure 4. Equation (3) may then be written

$$\frac{p_g - p_f}{3{\cdot}7} + 1283 \simeq \Delta z + z/30 - h/30. \qquad \ldots (4)$$

Of the three terms on the right-hand side of equation (4), $z/30$ is the adjustment to allow for surface pressure and $h/30$ for the height of the station above sea level.

As is seen from Table I, rain and snow were estimated to be equally likely at sea level when the magnitude of the right-hand side of equation (4) was 1293 gpm. Disregarding the third term, this means that if sea-level pressure is greater than 1000 mb a 50 per cent probability of snow exists with a 1000–850 mb thickness of less than 1293 gpm (by an amount $z/30$), and if the sea-level pressure is less than 1000 mb the reverse will hold. The reduction of 23 per cent in the number of failures as compared with the unadjusted 1000–850 mb thickness scarcely does justice to the importance of the correction on occasions when the sea-level pressure is markedly different from 1000 mb. For example, if the thickness were 1295 gpm and the sea-level pressure 980 mb the probability of snow would exceed 60 per cent. For the same thickness and a pressure of 1010 mb the probability would fall to 30 per cent.

In applying the pressure adjustment over the British Isles it is usually satisfactory to raise the numbering of the 1000–850 mb thickness lines by $(p_0-1000)/4$ gpm, where p_0 mb is the general level of sea-level pressure. Graphical addition of 1000–850 mb thickness lines (at 1-gpm intervals) to 4 mb isobars (1000 mb being subtracted from all pressures) is desirable only when there are very strong gradients in the sea-level pressure field.

The adjustment for height of the ground above sea level can be made by subtracting $h/30$ from the thickness adjusted for sea-level pressure and estimating the snow probability from Table I. Alternatively, if the 1000–850 mb thickness adjusted for pressure is, say, 1303 gpm, then the height when there is a 50 per cent probability of snow is $30(1303-1293) = 300$ gpm.

It was not possible to verify this relationship because there is no high-level radiosonde station in the British Isles. A possible source of error is the interpolation over high ground between low-level radiosonde stations. There is likely to be a lowering of the freezing-level as air crosses high ground and moreover the mean lapse rate between the freezing-level and the high ground may not be the same as the mean lapse rate below a freezing-level which is at the same height above low ground. From a comparison of the frequency of snow at Eskdalemuir (242 m above sea level) with frequencies at Aldergrove and Shanwell it appeared that these factors were not important, but only a somewhat crude test was possible.

(v) 1000– 700*mb thickness as a snow predictor.*—Whereas about three-quarters of the 1000–850 mb layer is above the freezing-level at the time when rain and snow are equally likely, the proportion in the 1000–700 mb layer is about seven-eighths. The deeper layer must therefore be the less precise of the two as a snow predictor.

(vi) 1000–500 *mb thickness as a snow predictor.*—This predictor appears to suffer from all the disadvantages of the 1000–700 mb thickness but to a greater degree. Its accuracy is only half that of the two best predictors, namely the height of the freezing-level and the adjusted 1000–850 mb thickness. It was noticed in particular that in southern parts of the British Isles snow occurred with quite high thickness because of the overrunning of warm air at heights far above the melting-level. Unusually warm air aloft gives a thickness which is unrepresentative of the capacity of surface layers to melt falling snow. Moreover, this lack of association means that the thickness at which rain and snow are equally likely depends on the set of observations analysed, and thus mainly accounts for the difference between the 5258 gpm found in this investigation and the 5224 gpm found by Murray.[1]

The forecasting of sleet.—As mentioned earlier, no independent method of forecasting sleet was found. It is most likely to occur when rain and snow are equally probable, when because of the variation in the initial sizes of snowflakes some have completely melted and others have not. It was found that at 0000 GMT, when sleet was falling, the surface temperature (in whole degrees Celsius) was 1°C or 2°C on 92 per cent of occasions. At 1200 GMT the temperatures covered a wider range because of surface heating, but 60 per cent were either 1°C or 2°C. The corresponding concentration of freezing-level heights between 30 and 40 mb above the ground has already been noted.

It is obvious that when the value of a predictor is such as to favour either rain or snow, the borderline situation for sleet is likely to occur less frequently. This is borne out by Figure 5, which shows the curve of frequency of sleet to follow quite well the curve of snow or rain, whichever is the less likely form of precipitation at the particular freezing-level height. In a forecast of precipitation form based on the height of the freezing-level the following features of Figure 5 are of interest:

(i) When rain and snow are equally probable, sleet is as likely as either.

(ii) If rain is wrongly forecast to be the form of precipitation, the alternatives of snow and sleet are equally likely.

(iii) If snow is wrongly forecast to be the form of precipitation, sleet is more likely than rain.

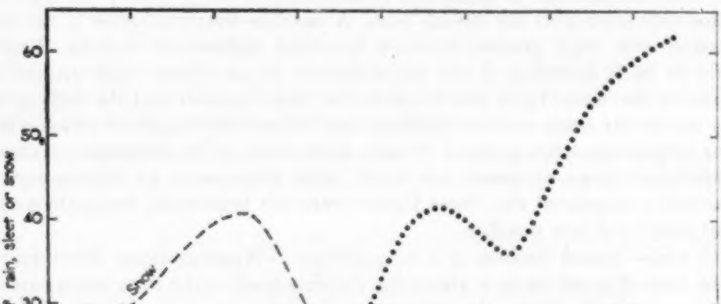

FIGURE 5—THE ASSOCIATION BETWEEN THE FREQUENCIES OF SLEET AND THE LESS LIKELY OF THE OTHER FORMS OF PRECIPITATION

REFERENCES

1. MURRAY, R.; Rain and snow in relation to the 1000–700 mb and 1000–500 mb thicknesses and the freezing level. *Met. Mag., London*, **81**, 1952, p. 5.
2. MURRAY, R.; Snow in relation to certain synoptic parameters. *Met. Mag., London*, **88**, 1959, p. 324.
3. LAMB, H. H.; Two-way relationship between the snow or ice limit and 1000–500 mb thicknesses in the overlying atmosphere. *Quart. J. R. met. Soc., London*, **81**, 1955, p. 172.
4. MINEEVA, M. N.; On forecasting the form of precipitation at the earth's surface. *Trudy Central'nogo Instituta Prognozov, Moscow*, Vyp. **83**, 1959, p. 28.
5. HEIMAT, J.; Nature des précipitations. *Paris, Mét. Nat., Notice d'Instructions techniques*, **15**, No. 12, 1958.
6. LANGLEBEN, M. P.; The terminal velocity of snowflakes. *Quart. J. R. met. Soc., London*, **80**, 1954, p. 174.
7. FINDEISEN, W.; Die Enstehung der 0°-Isothermie und die Fraktocumulus-Bildung unter Nimbostratus. *Met. Z., Braunschweig*, **57**, 1940, p. 49.
8. LUMB, F. E.; Cotswolds snowfall of 1 November 1942. *Met. Mag., London*, **89**, 1960, p. 11.

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STRATOSPHERIC CHANGES OVER THE BRITISH ISLES DURING ANTICYCLOGENESIS

By M. K. MILES

Introduction.—With the increase in the amount of data available from the stratosphere it has become evident from the studies of Godson,[1] Boville[2] and others that considerable changes occur from time to time in the winter circulation of the middle stratosphere, i.e. the part between about 50 mb and 10 mb. The changes extend over several days and it is natural to speculate, as Wilson and Godson[3] do, on the "possibility of the reflection of the tropospheric 'blocking high' situation in the stratospheric circulation."

It has been suggested by some American meteorologists that the large-scale features of the stratospheric circulation influence the perturbations of the tropospheric circulation with wavelengths greater than 120° of longitude, but generally, opinion in America and in Britain seems to favour an influence by the troposphere on the stratosphere.

Among Continental meteorologists opinion is much more in favour of a controlling influence by the stratosphere on the troposphere. Baur[4] and Attmannspacher[5] have suggested that changes in the circulation at the level of the ozonosphere (50 mb to about 5 mb) arising from changes in the incident long-wave ultra-violet radiation have important effects on the strength and latitude of the tropospheric west-wind belt. Scherhag[6] goes further and suggests that individual blocking anticyclones sometimes follow within a few days of stratospheric warmings. Wurlitzer[7] has put forward evidence that blocking over western Europe is closely related to the geomagnetic index—a connexion which clearly supposes a control from the high stratosphere, and Berkes,[8] in a study of variations in the latitude of blocking anticyclones during the sunspot cycle invokes the "Duell-Wurlitzer Effect," as he calls it, to explain what he found.

More recently Mironovitch[9] has presented his studies on blocking anticyclones and the accompanying changes in the stratosphere. He found in a sample of 26 cases that there was an associated "stratospheric perturbation" in 11 cases but in the other 15 cases the stratosphere up to 10 mb was "passive or presented a compensating effect." So inclined is he to find a stratospheric control that he supposes that in these 15 cases it must be located above 10 mb.

The idea that interruptions of zonal flow in the west-wind belt are induced by changes originating in the stratosphere is perhaps partly due to the failure

to explain them satisfactorily in terms of tropospheric events. Although the arguments for stratospheric control are not always very cogent the idea obviously cannot be dismissed without careful consideration. However at present it is not certain exactly what form or scale the stratospheric influence might have and considerable analytical study is required to gain some idea of this in order to see the problem in correct perspective. It is certainly dangerous to choose one phenomenon that happens occasionally in the stratosphere, be it a warming or a cooling or a change from bipolar to asymmetric flow and relate it to a much more frequent tropospheric occurrence such as anticyclogenesis. It is less dangerous (and it may help to clear the field a little) to study changes in the stratosphere that accompany anticyclogenesis.

This is done in the present paper for all cases of clear-cut anticyclogenesis occurring over or very near the British Isles for the months October to April inclusive from October 1958 to December 1962. Cases in which a pressure rise has occurred over Britain resulting from the extension of a ridge from a continental anticyclone have not been included, and neither have those cases in which an anticyclone centred in the Bay of Biscay has affected southern England for some time before a build of pressure occurring over Scotland has transferred the centre of the anticyclone to the northern North Sea or Scandinavia (a typical case of this sort in February 1962 is discussed but not included in the statistics).

The winter half of the year was selected for study in the expectation that if there is an influence from the stratosphere it will show up best in the season when the middle stratosphere is most active.

Observational data.—

(i) *Surface pressure changes.*—The criterion used in selecting the cases of anticyclogenesis was that there must be a substantial rise of pressure over the British Isles taking the general level of pressure from well below average to well above. This was required to happen over a period not longer than about four days and usually resulted in an anticyclone centred north of 50°N latitude, i.e. a blocking anticyclone. The pressures at Kew and Wick give a very good indication of the pressure pattern over Britain, and values for 1200 GMT were extracted for a period of six consecutive days for each case. The six days were chosen so that the anticyclogenesis was complete by day 4 or, at latest, day 5. In almost every case no substantial rise of pressure had set in by day 1. The dates of day 1 for the 17 cases in the statistics and 4 other cases which were looked at are given in an appendix.

Table I gives the average sea-level pressures at 1200 GMT for each of the six days at Kew and Wick as well as the mean of the two pressures: this can be regarded as typifying the sea-level pressure over England during each day of the process.

TABLE I—PRESSURES OVER BRITAIN DURING 17 CASES OF WINTER ANTICYCLOGENESIS

Day	1	2	3	4	5	6
			millibars			
Kew	1008.8	1012.5	1020.4	1029.1	1031.2	1030.1
Wick	996.3	1003.7	1015.4	1025.5	1026.9	1028.0
Average of Kew and Wick	1002.6	1008.1	1017.9	1027.3	1029.0	1029.0

These means indicate that the period of most rapid surface rise of pressure has been centred fairly satisfactorily between days 2 and 4 and the rise is virtually complete by day 5.

(ii) *Contour height changes aloft.*—Representative values of the level of the 200, 100 and 50 mb pressures were obtained for a central point over Britain. This was done by extracting the values obtained at 0000 GMT and 1200 GMT from the radiosonde stations at Aughton and Hemsby and plotting them on a time graph. When observations were missing or appeared obviously anomalous, values from Crawley, Aldergrove or Shanwell radiosonde stations were added to the graph. A smooth curve was then drawn through these points for each of the three levels, and from these curves values for 1200 GMT for each of the six days were read off. The means of these for 17 cases are given in Table II.

TABLE II—HEIGHTS AT VARIOUS PRESSURE LEVELS OVER ENGLAND DURING ANTICYCLOGENESIS

Day	1	2	3	4	5	6
			decametres			
200 mb	1163	1161	1169	1178	1181	1178
100 mb	1602	1601	1605	1611	1613	1613
50 mb	2039	2038	2039	2043	2047	2048

These values and the appropriate sea-level pressures are plotted together in Figure 1.

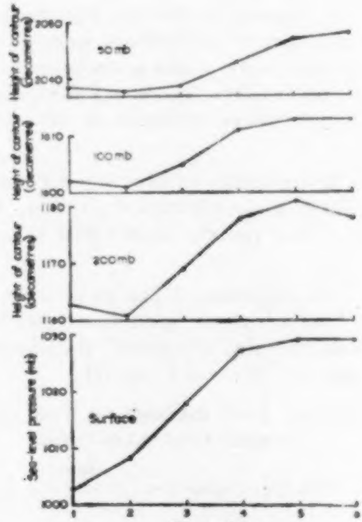

FIGURE 1—MEAN CHANGES IN SEA-LEVEL PRESSURE AND CONTOUR HEIGHT AT 200 MB, 100 MB AND 50 MB DURING ANTICYCLOGENESIS OVER BRITAIN

At 200 mb, which can be considered the top of the troposphere, the course of events closely resembles that at the surface, with the steepest height rise between days 2 and 4.

In the stratosphere the rate of height rise is less and decreases upwards. At 50 mb the period of steepest rise occurs one day later than that at 200 mb.

The slight fall of height at 200 mb between day 1 and 2 is almost certainly real and corresponds to the passage of a thermal trough in the upper troposphere just before the onset of anticyclogenesis in over half of the cases.

The height rise at 50 mb is almost entirely due to two cases—January 1959 and December 1962. In both of these the 50 mb height at day 1 was below the average value for the season based on the monthly means given in appendix 2. Apart from two other cases which however produced rises of only 7 and 10 decametres between day 1 and day 6, the 50 mb height at day 1 was above the seasonal average for day 1. In fact the mean for the 17 cases was +5 decametres, compared with a mean of +2 decametres at 200 mb with equal numbers above and below the average.

The occasion in February 1962 is especially interesting in this connexion. Although the 200 mb height was 16 decametres above normal on day 1 (obviously associated with the warm anticyclone already in existence just to the south-west of the British Isles) the 50 mb height was 25 decametres below normal. By day 6 the 200 mb height had risen only 6 decametres but the 50 mb height was 49 decametres higher than on day 1. Summing up it can be said that while in the majority of cases the 50 mb height rises far less than that at 200 mb there were three cases with a rise greater than 15 decametres (i.e. the mean rise at 200 mb from day 1 to day 4) and in two of them the 50 mb height was untypically below the seasonal average on day 1. The three cases of anticyclogenesis in 1963 (looked at after the statistics had been compiled) do not however fit into this pattern particularly well. The 50 mb heights in the February and March cases were 7 and 4 decametres respectively below the seasonal mean on day 1 and neither showed any rise during the anticyclogenesis. The April case was slightly above the mean on day 1 and rose 11 decametres during the six days.

It would obviously be premature to form any conclusions about the circumstances under which the 50 mb height rises appreciably during anticyclogenesis. All that can be said is that the rise equals that at 200 mb in only a small minority of cases.

(iii) *Wind changes in the stratosphere.*—The 24-hour vector wind changes were computed from the Aughton radar wind observations supplemented where necessary by values from Hemsby. The mean values for each of the five 24-hour intervals for the 17 cases are given in Table III.

TABLE III—24-HOUR VECTOR MEAN CHANGES OF WIND OVER CENTRAL ENGLAND DURING ANTICYCLOGENESIS

	Day 1–2	Day 2–3	Interval Day 3–4 *degrees/knots*	Day 4–5	Day 5–6
200 mb	020/6	040/25	100/8	140/22	050/13
100 mb	330/2	045/15	080/3	150/9	040/5
50 mb	360/1	025/10	090/6	090/2	165/2

As these means are made up of rather variable components the distribution by quadrants of the individual values is given in Table IV to help in the assessment of their significance.

The marked concentration of these values in the two eastern quadrants implies a reduction in the strength of the prevailing west to north-west wind (average 200 mb wind on day 1 was 274° 46kt). The concentration in the

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PLATE I—HAAR OVER THE EDEN ESTUARY AT 1145 GMT ON 5 JUNE 1964

(see p. 379)

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PLATE II—HAIL STONES BLOCKING A STREET IN BURNLEY AFTER THE HEAVY STORMS IN EAST LANCASHIRE ON 18 JULY 1964

During the storm 1.36 inches of rain fell in 15 minutes in Nelson, Lancashire, about 4 miles from Burnley.

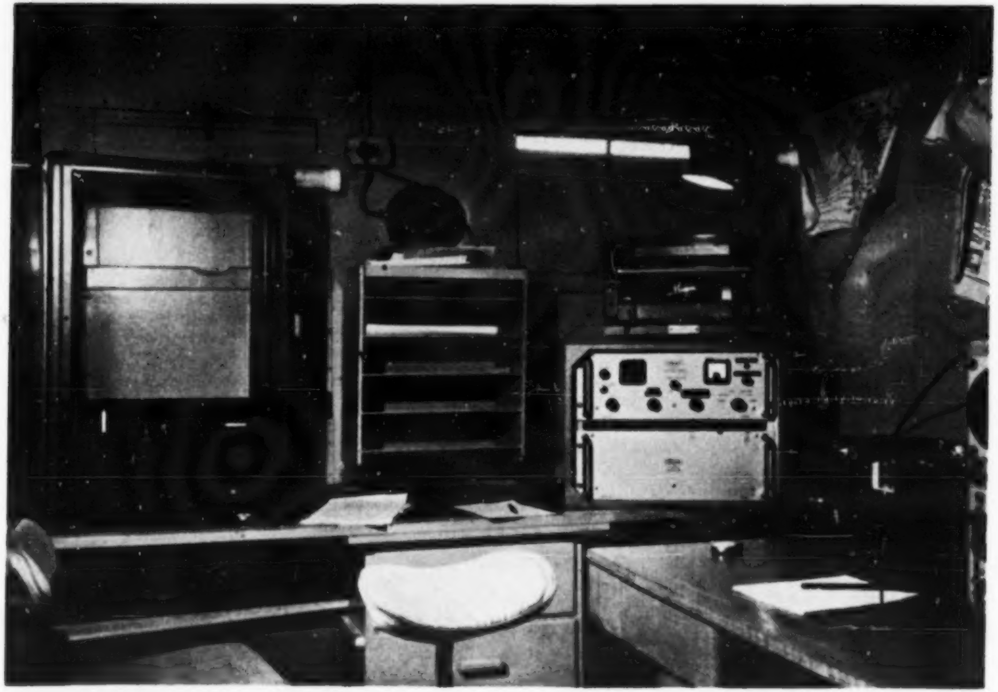

PLATE III—METEOROLOGICAL OFFICE EQUIPMENT FOR RECEIVING AUTOMATIC CLOUD PICTURE TRANSMISSIONS FROM THE AMERICAN SATELLITE 'NIMBUS A'

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PLATE IV—METEOROLOGICAL OFFICE CLOUD PICTURE RECEIVING AERIAL AT THE EXPERIMENTAL SITE NEAR BRACKNELL

'NIMBUS A' was launched at midday on 28 August 1964 and continues an experimental series which started with the satellite TIROS VIII. Cloud pictures, as seen from very high levels, will form very valuable additional material for meteorology when regular information covering all parts of the world is available. At this stage, the main interest of the Meteorological Office is to develop economic British-made receiving equipment and to make preliminary assessments of the value of this new form of information, together with the means by which it may be assimilated into routine weather forecasting. Unfortunately 'NIMBUS A' ceased transmitting on 23rd September, but further experimental satellites are planned.

TABLE IV—DISTRIBUTION BY QUADRANTS OF 24-HOUR VECTOR WIND CHANGES OVER CENTRAL ENGLAND DURING ANTICYCLOGENESIS

Interval	Day 1–2			Day 2–3			Day 3–4			Day 4–5			Day 5–6			All days		
Pressure level mb	200	100	50	200	100	50	200	100	50	200	100	50	200	100	50	200	100	50
Direction quadrant	*number of occasions*																	
005–090°	5	4	2	10	8	5	8	7	1	3	2	2	5	5	2	31	26	12
095–180°	5	3	3	1	2	2	4	3	3	7	9	1	5	1	3	22	18	12
185–270°	3	2	1	2	1	0	2	4	1	5	3	2	3	1	3	15	11	7
275–360°	4	4	1	4	2	1	3	0	0	1	0	0	3	1	0	15	7	2
Variable, less than 10 knots	0	4	8	0	4	8	0	3	10	1	3	10	1	9	8	2	23	44

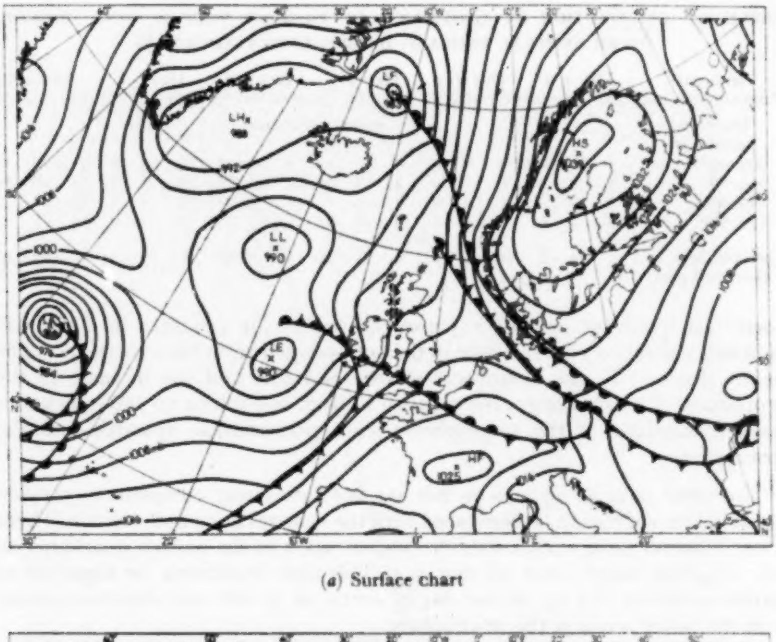
north-east quadrant on day 2–3 and the size of the resultant in Table III indicates a wind veer at this stage in the anticyclogenesis at the three levels. The steady decrease in the magnitude of the resultants and the increase in the proportion of wind changes less than 10 kt from 200 mb to 50 mb indicates a marked damping of the tropospheric wind perturbation upwards into the stratosphere.

The wind data at 25 and 30 mb are not sufficiently complete to provide mean values which can be compared with the changes at 50 and 100 mb. There is not however quite such a notable concentration in the eastern quadrants on day 2–3, but rather more on day 3–4. This may tentatively be regarded as further evidence of a lag of one day in events at 50 mb and above compared with the lower levels of the stratosphere.

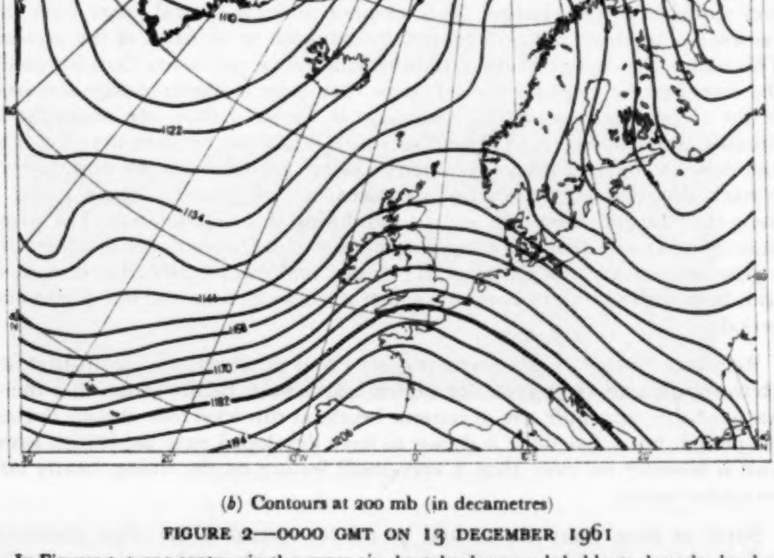
Discussion of individual cases.—The anticyclogenesis of December 1961 has been illustrated by synoptic charts in order to convey an idea of the scale and sequence of the changes. This situation is fairly typical apart from the presence of a strong anticyclone over Scandinavia at the start of the process. This makes the change in the surface situation look rather less than is usually the case, but the maps for 200 mb show that quite a drastic change occurred in the tropospheric westerlies. The maps in Figure 2 show the tropospheric situation at 0000 GMT on 13 December which is midway between days 2 and 3, and those in Figure 3 show the situation 48 hours later when the tropospheric perturbation had almost reached its maximum amplitude. Figures 4 and 5 show the changes at 100 mb and 50 mb during this time interval. The maps show quite clearly that the anticyclogenesis over Britain was accompanied by a great amplification of the ridge at 200 mb, and this amplification decreased with height above the tropopause (which was mostly near 200 mb during the period).

Reference to the 10 mb charts prepared and published by the Institut für Meteorologie und Geophysik der Freien Universität, Berlin, shows that there was probably very little rise of contour height at this level over Britain during the period, but a flat ridge is shown to have developed near the British Isles. This is however no more than a very small feature on the strong, nearly circumpolar vortex.

Study of these charts for 10 and 30 mb for several of the other situations indicated that the ridge amplification decreased with height and was usually insignificant at some level between 30 and 10 mb and occasionally by 30 mb.



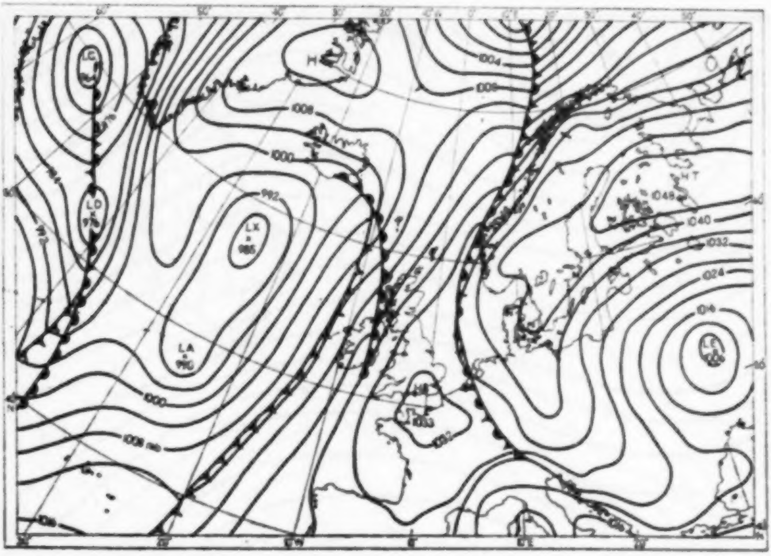
(*a*) Surface chart



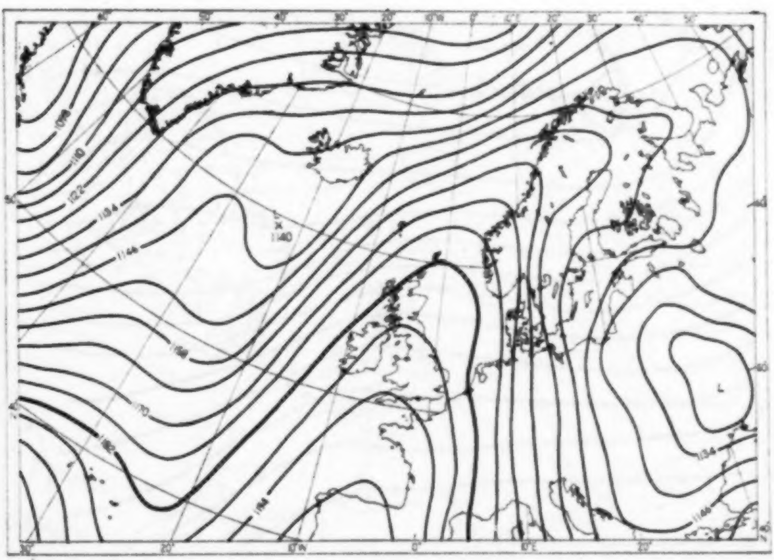
(*b*) Contours at 200 mb (in decametres)

FIGURE 2—0000 GMT ON 13 DECEMBER 1961

In Figures 2–5 one contour in the upper air charts has been made bolder to show the development of the ridge at each level.

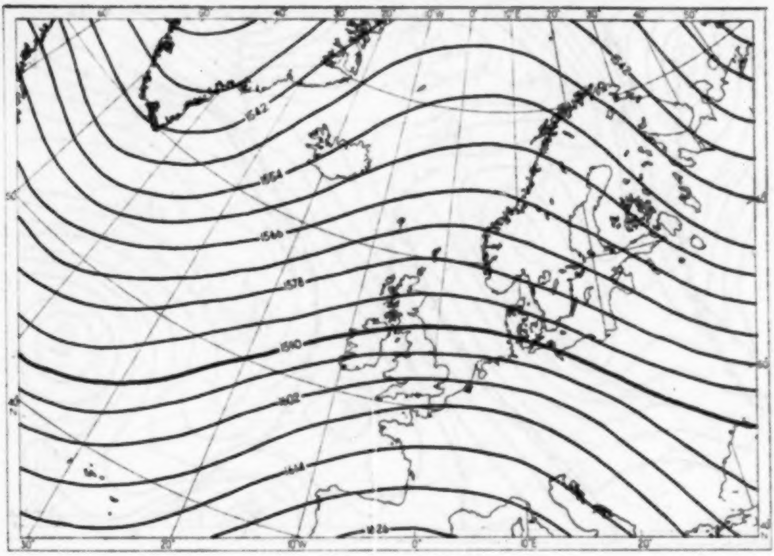


(*a*) Surface chart

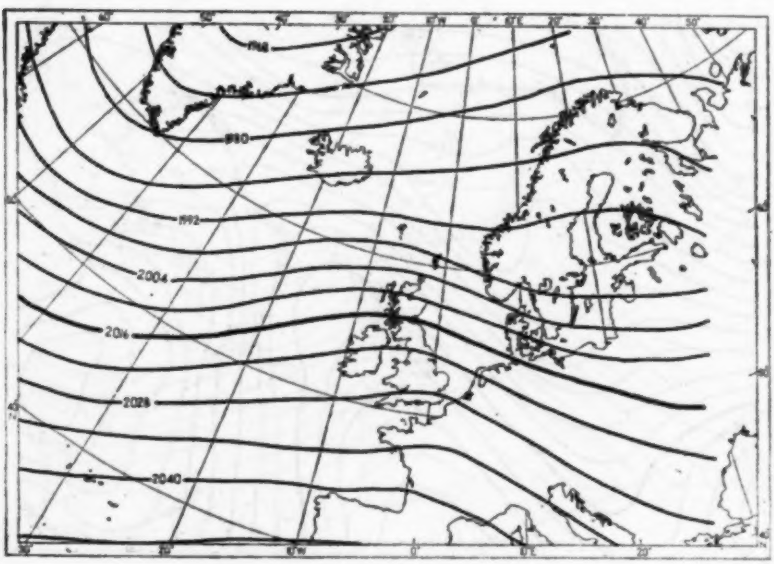


(*b*) Contours at 200 mb (in decametres)

FIGURE 3—0000 GMT ON 15 DECEMBER 1961

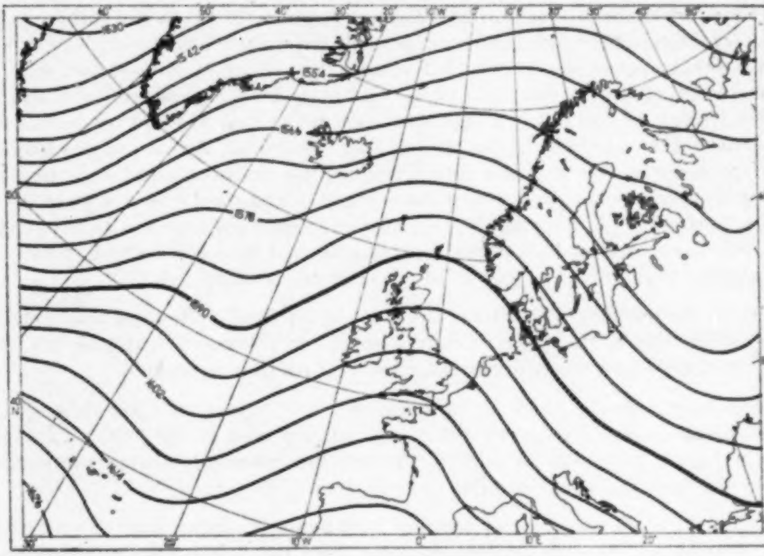


(*a*) Contours at 100 mb (in decametres)

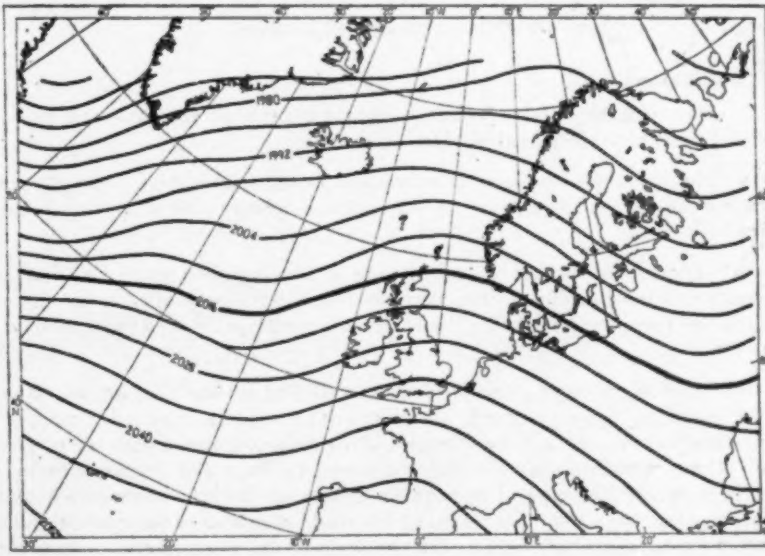


(*b*) Contours at 50 mb (in decametres)

FIGURE 4—0000 GMT ON 13 DECEMBER 1961



(*a*) Contours at 100 mb (in decametres)



(*b*) Contours at 50 mb (in decametres)

FIGURE 5—0000 GMT ON 15 DECEMBER 1961

One such occasion was during the anticyclogenesis of 14–16 November 1958. In fact the contour heights at 10 mb actually fell slightly from 13–16 November as a trough moved south towards England. The situation in the lower stratosphere was also somewhat untypical. On 13 and 14 November there was a strong ridge at 100 mb over the east Atlantic so that the 100 mb winds at Aughton were northerly at the start of anticyclogenesis. As the contour height at 100 mb rose over England the strength of this northerly wind decreased so that the vector changes between days 2 and 3 and days 3 and 4 were 200° 11 kt and 200° 15 kt respectively, i.e. contrary to the most common direction. At 25 mb however the winds started by being around 300° and backed to 280°—changes symptomatic of those at 10 mb referred to earlier.

With the blocking which was completed on 14 April 1962 there was a clear lag of one day in the ridge formation at 30 mb compared with 100 mb. At 10 mb there was a much flatter ridge by the 14th than at 30 mb.

Similarly with the block set up between 3 and 6 January 1960 although a well-marked ridge had developed at 100 mb just west of the British Isles, at 30 or 10 mb there was no ridge in the west-north-westerly airflow round the cold vortex near Novaja Zemlja.

With the block set up by 17 October 1958 a closed contour high at 50 mb at 45°N 25°W on the 14th had moved away from the British Isles to a position 40°N 35°W on 16 October.

A warm stratospheric high centred over the Bay of Biscay was in existence for a week or more before the rather short-lived blocking at the end of January 1962. It neither strengthened nor moved nearer to the British Isles during the period of anticyclogenesis between 26 and 28 January.

Conclusions.—

(i) Anticyclogenesis over Britain is almost invariably accompanied by the development of a fairly peaked ridge at 200 mb.

(ii) The sharpness of this ridge is reduced as the stratosphere is penetrated. There is usually a flat ridge at 50 mb, but it is usually absent by 10 mb and often by 25 mb.

(iii) The height rise at 50 mb during anticyclogenesis exceeded that at 200 mb only once in the 21 cases examined. In the majority of cases the rise at 50 mb was considerably smaller than that at 200 mb and tended to happen one day later.

(iv) Most of the cases of anticyclogenesis studied involved an amplification of the waves in the tropospheric westerlies with a spacing of no more than 30° longitude between the upwind trough and the ridge associated with the surface anticyclone. This is not on the scale envisaged by Baur and Attmannspacher, but is probably the type of occurrence Scherhag, Berkes, Mironovitch and Wurlitzer have in mind. The results of this study do not seem susceptible of the kind of explanation they favour. On the scale of the tropospheric process the primary effect appears to be in the troposphere, but this does not of course rule out the possibility that some larger-scale change in the stratosphere some days earlier was responsible for the distortion of the tropospheric westerlies.

Appendix 1

Dates of 'day 1' for 17 cases of anticyclogenesis

15 October 1958	3 January 1960	9 January 1961	1 October 1962
13 November 1958	3 February 1960	9 October 1961	23 November 1962
22 January 1959	1 March 1960	11 December 1961	18 December 1962
5 March 1959	13 April 1960	25 January 1962	
16 April 1959		10 April 1962	

Dates of 'day 1' for other cases mentioned in text

17 February 1962	20 March 1963
19 February 1963	22 April 1963

Appendix 2

Monthly averages of contour height (mean of Aughton and Hemsby) for 1958–62:

	Oct.	Nov.	Dec.	Jan. *decametres*	Feb.	Mar.	Apr.
200 mb	1180	1164	1151	1150	1159	1155	1163
50 mb	2054	2032	2019	2000	2046	2037	2048

REFERENCES

1. GODSON, W. L.; Total ozone in the middle stratosphere over arctic and sub-arctic areas in winter and spring. *Quart. J. R. met. Soc., London*, **86**, 1960, p. 301.
2. BOVILLE, B. W.; The Aleutian stratospheric anticyclone. *J. Met., Lancaster, Pa.*, **17**, 1960, p. 329.
3. WILSON, C. V. and GODSON, W. L.; The structure of the arctic winter stratosphere over a 10-yr period. *Quart. J. R. met. Soc., London*, **89**, 1963, p. 205.
4. BAUR, F.; Grosswetterkunde und langfristige Witterungsvorhersage. Frankfurt am Main, Akademische Verlagsgesellschaft, 1963, p. 62.
5. ATTMANNSPACHER, W.; Über den Zusammenhang zwischen der troposphärischen und stratosphärischen Zirkulation. Baur, F.; Grosswetterkunde und langfristige Witterungsvorhersage. Frankfurt am Main, Akademische Verlagsgesellschaft, 1963, p. 63.
6. SCHERHAG, R.; Stratospheric temperature changes and the associated changes in pressure distribution. *J. Met., Lancaster, Pa.*, **17**, 1960, p. 575.
7. WURLITZER, G.; Das Verhalten des Luftdrucks am Boden bei Schwankungen der erdmagnetischen Aktivität. *Met. Abh. Freien Universität, Berlin*, **7**, 1958.
8. BERKES, Z.; Auswirkung der Sonnentätigkeit auf der Luftdruckverteilung. *Időjárás, Budapest*, **65**, 1961, p. 22.
9. MIRONOVITCH, V.; Interruptions of zonal tropospheric flow in western Europe. *Met. Abh. Freien Universität, Berlin*, **36**, 1963, p. 77.

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MEETING ON THE METEOROLOGICAL ASPECTS OF SUPERSONIC TRANSPORT OPERATIONS

By A. A. WORTHINGTON, B.Sc.

A meeting on the meteorological aspects of supersonic transport was held on 29 June 1964 in the Lecture Room of the Meteorological Office, Bracknell. It was attended by representatives from the Guild of Air Pilots and Navigators, the British Airline Pilots' Association, the Ministry of Aviation, the Air Registration Board, the Imperial College of Science and Technology and the Meteorological Office.

The Chairman, Mr. P. J. Meade, Deputy Director of the Meteorological Office, in his opening address, stated that the purpose of the meeting was largely informative. Specialist speakers drawn from the Meteorological Office would, he said, discuss various meteorological subjects of importance to the operation of supersonic transport. In doing so, they would outline the work now in progress and the plans for further research. The particular problems of

cosmic radiation and atmospheric electricity would however not be discussed since they were somewhat outside—at least at present—the fields of research covered by the Office.

Some aspects of organization and operational procedures were reviewed by Mr. A. A. Worthington. His main theme was the need for co-ordination in effort in preparing for the advent of supersonic transport in the early 1970's. The International Civil Aviation Organization (ICAO) and the World Meteorological Organization (WMO), he said, were undoubtedly aware of the coming needs. He cited the findings of the recent Joint Session of the Meteorology and Operations Divisions of ICAO and the Commission for Aeronautical Meteorology of WMO and also the recent action taken by the Executive Committee of WMO. It was now, he continued, largely a question of planning in detail. He pointed in particular to the need for development of networks of regular and reliable radiosonde and radiowind ascents to 80,000 feet and said, in this regard, that the time factor involved in translating international agreement into practice had to be borne in mind. After all, 1970 was not very far away.

Wind and turbulence near the ground were discussed by Dr. A. G. Forsdyke. His talk was mainly on meeting the operational requirements for information on these elements, requirements which were as much for present-day jet aircraft as for future supersonic aircraft. There were, he said, the problems of meeting the requirements for actual and forecast information on light surface winds, on gusts and gustiness and on vertical wind shear. There was also the requirement to be considered for the supply of wind information in component form related to the runway in use. He discussed the characteristics of wind structure in the lower layers of the atmosphere. It was his opinion that the operationally desired accuracies were not yet attainable and that much more work would have to be done before any conclusions could be reached as to how far the accuracies could be achieved. In listing the ways in which such work could be undertaken, Dr. Forsdyke referred in particular to the mounting of sensitive anemometers at various heights on masts at strategic sites on airfields. This he thought would probably be found to be the best method for further investigation of the wind structure near the ground. In the discussion which followed it was learnt that a new sensitive anemometer was now under test which could, in addition to being responsive to light winds, provide wind speed data in component form.

Winds and temperatures in the upper air were discussed next. Mr. C. L. Hawson spoke about the layer of the atmosphere bounded by the 100 mb and 50 mb surfaces. He listed points concerning the wind and temperature systems in that layer. The systems tend to be very large, the lower stratosphere acting as a filter so that the shorter wave-length disturbances decay rapidly with increasing altitude. The systems are mostly slow moving. In temperate and northern latitudes the systems, he said, are very dependent on the season. There is marked similarity in the patterns of different summers but, on the other hand, large changes are found in the patterns of different winters. In the late winter and spring extraordinary wind and temperature systems occasionally develop and Mr. Hawson referred to 'explosive warming' in which an area of warm air developed rather quickly. Such development he considered was associated with vertical motions originating, in some cases, in levels much

above the 10 mb surface. In the tropical belt, Mr. Hawson said, the seasonal variation is very different from that in higher latitudes and shows a fluctuation in zonal wind component with a period of about 26 months. Mr. Hawson commented on the difficulties of high-level analysis: difficulties which arose mainly from the fact that errors associated with geopotential height determination of a radiosonde observation are cumulative with altitude, that the effect of errors induced by solar radiation increases with decreasing density and that the number of upper air observations decreases with altitude. Current analyses used as forecasts for intervals up to at least 24 hours ahead, Mr. Hawson thought, would be perhaps more accurate than forecasts utilizing techniques applicable to the troposphere. However, he pointed out that using current analyses would not hold in the case of 'explosive warming'; forecasting the change in respect of this phenomenon would be necessary. Mr. Hawson also pointed out that one further consequence of the tendency for persistence was that if, for some reason, a stratospheric disturbance interfered with a particular operation then it could be a week or more before a change in the situation could be expected. In discussion it was noted that the operation of supersonic aircraft could well be limited by temperature. It was said that 'explosive warming' had posed some questions yet to be answered. However, the impression was that the general effects of temperature on aircraft performance were known.

Mr. J. Briggs followed with a discussion on turbulence in clear air and in cloud. He concentrated on those features of the high troposphere and of the stratosphere which may be expected to produce turbulence for supersonic aircraft. The problem, he said, is complicated by the fact that atmospheric turbulence may not necessarily cause aircraft 'bumps' owing to the selective response of the aircraft to input at different frequencies. On the other hand, laminar airflow would not necessarily mean smooth flight since the high speed of traverse across successive up and down flows of the air pattern may create an impulse cycle close to one of the natural frequencies of the aircraft structure. In general, the frequency range of interest, he said, is from 0.1 to 10 cycles/second. Conventional aircraft have mainly responded to disturbances or eddies of the order in size of 50 feet to 6000 feet, but the important size for the supersonic aircraft may well be 20,000 feet or more. On convective turbulence Mr. Briggs said the most serious cases are likely to occur in or near cumulonimbus cloud. The size of a cumulus cloud is a rough guide to the strength of the vertical currents, and so of turbulence in or near the cloud. Cumulonimbus, he said, is characterized not only by its size and vigour but by its persistence and the presence of strong down draughts. Further, it seems likely that the strongest currents will occur in the middle and upper parts of the cloud, which may extend to the tropopause or beyond. The presence close together of intense up and down draughts may not in itself contribute to severe bumpiness during a traverse but at supersonic speeds, even allowing for the appreciable horizontal dimensions, the strong shear at the edges of these draughts is likely to create extra turbulence and the gust speeds, as distinct from draught speeds, may be very large. Severe convective turbulence has been experienced, he said, at heights up to 65,000 feet. Mr. Briggs turned next to non-convective turbulence; an expression, he said, which covered several mechanisms of which knowledge is still very limited. Some bumpiness will occur in the crossing of temperature discontinuities, some from resonance effects in crossing laminar flow, such as

mountain-induced waves, and some will be due to true atmospheric turbulence. Analyses of reported non-convective turbulence in relation to synoptic situations have shown that some 70 per cent of occurrences are associated with jet streams. Examinations of links with smaller-scale features have not been very successful but it does seem, he said, that vertical shear of wind and the static stability of the air are the most significant. Mr. Briggs stressed that even for traverses of jet streams the frequency of turbulence, of intensity greater than slight, is low. He went on to say that the most severe cases of clear-air turbulence have usually been found associated with mountain waves and the effect of such waves could extend well up into the stratosphere. Mr. Briggs suggested that the forecasting of turbulence in other than very general terms seemed a long way off and perhaps unrealizable. In discussion it was felt that perhaps the most hopeful solution lay in the forward detection of turbulence by an aircraft and in this connexion it was noted that with supersonic aircraft it may be necessary to make a decision regarding diversion as much as 200 miles away from an area of turbulence.

Mr. R. F. Jones outlined the present position regarding information on cloud, precipitation and ozone. He dealt at some length with hail. The thunderstorm, he said, with its associated hail and turbulence represented perhaps the greatest meteorological hazard to aviation, supersonic or otherwise. However, the hazard must be considered in proportion. For many routes and for certain times of the year the problem was non-existent as regards the cruise phase of supersonic operations. Within any thunderstorm and within many a cumulonimbus cloud at some stage of its existence, it is highly probable that there is a core containing hail but, judging from evidence available, the horizontal extent of the hail core compared with the total extent of the cloud is almost certainly small. On a particular flight the low probability of being within a cumulonimbus cloud multiplied by the low probability of being within that part of the cloud with hail and the low probability that the hail will be above a significant size, indicates that the chances of a hazardous hail encounter are very small indeed. Putting figures to the chances, he said, was however not easy. As regards forecasting storms, Mr. Jones doubted whether a forecaster will ever be in a position to forecast for more than perhaps an hour or so ahead (and this assumes an accurate and up-to-date knowledge of actual conditions) that a storm will or will not be in a certain precise place at a certain time. However, if there is a storm somewhere the forecaster may be able to give some guidance on the likelihood of it containing large hail. Also the forecaster should be able to say whether conditions are favourable for the development of storms or not. It follows, Mr. Jones said, that if it is critically necessary for the aircraft to avoid storms either in cruising flight or, more likely, in the transonic phase, then precise up-to-the-minute information of the presence and position of storms will be required together with the means of informing the pilot. He suggested that perhaps the best answer to the problem of hail was the avoidance of all active cloud and in this, no doubt, airborne radar would be essential. Mr. Jones went on to discuss icing and ozone. Icing caused by the interception of supercooled cloud droplets seems, he said, likely to occur mostly in the subsonic phase of flight and so will present the same problems as for present-day aircraft accentuated perhaps by the smaller radii of curvature of leading edges and perhaps by a greater susceptibility to any modification of airflow caused by icing. As regards ozone, there appeared to

be adequate information. Mr. Jones also referred to sonic boom. He said that until the precise nature and accuracy of the meteorological data which may be required in sonic boom accountability are known it would not be possible to say whether or not present radiosonde networks would be adequate.

A general discussion followed which ranged over quite a number of points including the incidence of cumulonimbus cloud tops above 55,000 feet, thermal gusts, erosion aspects of precipitation, the maximum concentration of ozone which could be encountered and methods of obtaining further meteorological data for the supersonic operating levels.

The Chairman, in closing, expressed his appreciation of the presentations by the speakers of the various subjects discussed. He felt that a lot of good had been derived from meeting together and discussing the meteorological problems relating to the operation of supersonic transport.

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TIDAL EFFECTS ON THE DISSIPATION OF HAAR

By L. L. ALEXANDER

The Eden estuary forms the southern boundary of Leuchars airfield and joins the open sea about 1½ miles east-south-east of Leuchars. At this point, it is about 1 mile wide at high tide and funnels to about ¼ mile wide in the 3 miles of tidal water which ends at Guard Bridge (1 mile south-west of the airfield). At low tide, extensive areas of sand and mud are rapidly uncovered, so that the estuary is effectively a land surface. West of Guard Bridge, the Eden is only a small and insignificant stream (Figure 1).

The photograph (Plate I) illustrates the effect of the tidal waters of the Eden estuary on the clearance of haar at Leuchars. The photograph was taken at 1145 GMT on 5 June 1964, and is looking south-east. High tide was at 0950 GMT. The sea temperature measured at Bell Rock was 9°C.

A spell of haar had started at 0800 GMT on 4 June and there had been 8/8 continuous low stratus, the base varying between the surface and 800 feet.

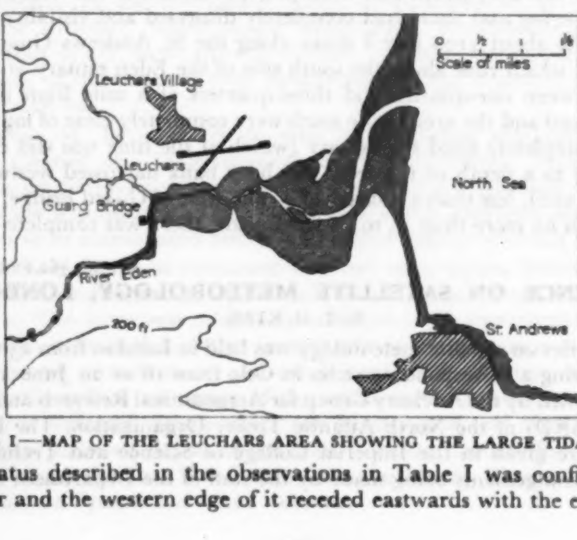

FIGURE 1—MAP OF THE LEUCHARS AREA SHOWING THE LARGE TIDAL AREA

The stratus described in the observations in Table I was confined to the tidal water and the western edge of it receded eastwards with the ebbing tide.

The stratus could be seen to be moving from the east with the wind and disappearing as it reached the edge of the water surface.

TABLE I—OBSERVATIONS AT LEUCHARS, 5 JUNE 1964

Time GMT	Surface wind *Direction*	*Speed*	Visibility	Cloud	Temperature °C Dry-bulb	Dew-point
0848	140°	4 kt	500 yd	5/8 at surface 8/8 at 300 ft	11.5	11.5
0948	090°	6 kt	3000 yd	1/8 at surface 2/8 at 300 ft 2/8 at 2000 ft	12.7	12.3
1035	120°	9 kt	1600 yd from E to SW 2–3 n.miles elsewhere	2/8 at surface 2/8 at 2500 ft	—	—
1050	110°	10 kt	500 yd	5/8 at surface 2/8 at 2500 ft	13.2	11.9
1148	070°	7 kt	2000 yd to SE 16 n.miles elsewhere	1/8 at surface 2/8 at 3000 ft	14.4	12.4

It is well known locally that the tidal waters of the Eden have an effect on the formation and dissipation of haar on the airfield. The reverse of the process described above has often been seen with incoming tides. Similar effects have been described by Lawrence[1] and Watts.[2]

The increase in low stratus between 1035 and 1050 GMT illustrates the speed with which stratus can move onto the airfield (probably because of a change in wind direction, though this cannot be confirmed because of the distance of the anemograph from the stratus at the critical time).

By 1227 GMT the stratus had cleared from the vicinity of the airfield. Bell Rock was in fog (visibility less than 220 yards) from 0300 to 1500 on 5 June.

REFERENCES

1. LAWRENCE, E. N.; Whirlwind at Southend-on-Sea, August 10, 1953. *Met. Mag., London*, **83**, 1954, p. 4.
2. WATTS, A. J.; Sea-breeze at Thorney Island. *Met. Mag., London*, **84**, 1955, p. 42.

Additional observation by A. S. Russell.—In confirmation of Mr. Alexander's note, the visibility was 300 yards and the cloud base below 100 feet at 0700 GMT on 5 June at St. Andrews, 4 n.miles south-east of Leuchars. By 0800 GMT the fog and cloud had completely dispersed and visibility was 1½ to 3 n.miles. At about 1100 GMT I drove along the St. Andrews–Guard Bridge–Cupar road which runs along the south side of the Eden estuary at a distance varying between one-quarter and three-quarters of a mile from the estuary edge. The road and the area to the south were completely clear of fog and cloud but haar completely filled the estuary (which at the time was still covered by tidal water) to a depth of 150 feet. The haar bank narrowed westwards with the estuary until, less than a quarter of a mile west of Guard Bridge, where the river Eden is no more than 15 to 20 yards wide, there was complete clearance.

551.507.362.2:061.3:621.397

CONFERENCE ON SATELLITE METEOROLOGY, LONDON 1964

By T. H. KIRK

A lecture series on satellite meteorology was held in London from 23 to 26 June 1964, following a corresponding series in Oslo from 16 to 20 June 1964, both being promoted by the Advisory Group for Aeronautical Research and Development (AGARD) of the North Atlantic Treaty Organization. The lectures in London were given in the Imperial College of Science and Technology, all necessary arrangements being made by the staff of the Department of Meteorology.

The lecturers were Dr. S. Fred Singer, Dean of the School of Environmental and Planetary Sciences, University of Miami, and the specialists: Dr. Philip M. Diamond, Meteorological Satellite Study, Aerospace Corporation; Mr. David W. Holmes, Deputy Director, Operations, National Weather Satellite Center, Weather Bureau; Mr. Lester F. Hubert, Synoptic Meteorology Branch, National Weather Satellite Center; and Professor Verner E. Suomi of the University of Wisconsin. Representatives of many European countries and organizations attended the lectures; those from the United Kingdom included staff of the Meteorological Office and of industrial concerns.

After a welcoming speech by Professor P. A. Sheppard, C.B.E., F.R.S., Head of the Department of Meteorology, Imperial College, Dr. Singer opened the series with a comprehensive review of the subject, dealing first with the general principles of design of a national operational meteorological satellite system; in particular, the considerations governing the choice of orbits, what can be observed and the sensors that are now available to make the observations, how to use the data once obtained and finally the factors relevant to the important aspect of minimizing the overall cost.

The satellite views the atmosphere by both emitted and scattered radiation which ranges from the ultra-violet through the visible part of the spectrum to the infra-red and microwave bands. From the ultra-violet and visible parts of the spectrum the data usage can be listed under the general headings, meteorological, non-meteorological and economic. The meteorological data relate to ozone, airglow, emissions from atmospheric constituents, cloud patterns, fronts, cyclones, storms, and jet streams. Non-meteorological data include those of ice, snow, soil properties, insect clouds, sea state, while on the economic side there are geological features, crops and vegetation, droughts and floods, large-scale constructions, terrain features, coast lines and mineral resources. The infra-red sensors provide meteorological information on surface temperature, water vapour distribution, cloud heights and atmospheric structure, and non-meteorological information such as forest fires and other conflagrations, volcanoes and ocean currents. In the microwave band, information can be provided on atmospheric structure, water vapour distribution, precipitation, sferics, and the properties of soil, snow and ice surfaces. In short, the satellite provides a wide variety of information, both meteorological and non-meteorological, of great potential use.

Dr. Philip M. Diamond dealt with the following engineering aspects: Attitude Control for Meteorological Satellites; Electric Power Systems; Miscellaneous Sub-systems; and, finally Systems Cost Analysis. His detailed analysis gave a considerable insight into the many problems and difficulties which had to be surmounted before the satellite project achieved its success.

Mr. D. W. Holmes was concerned with two main topics, Television Sensors and Cameras and secondly, Operational Data Transmission, Processing and Utilization. The scope was admirably outlined in his introduction: "It is no exaggeration to state that nature uses clouds to draw its own weather map; satellites permit us to both see and use this map. The function of the camera is to optically collect an image of the sunlit earth cloud-cover and correct the image to electrical signals which can be processed and transmitted to the users." Then followed details of the TIROS Vidicon Camera System, the Advanced Vidicon Camera Sub-System, the Automatic Picture Transmission (APT) Camera System and future cameras.

It is the APT which provides a means for local read-out of cloud cover from weather satellites, given suitable reception facilities of relatively modest cost. This sub-system was installed first in TIROS VIII and is incorporated in the NIMBUS satellite. Pictures already received from both these satellites have confirmed the possibilities of APT as a forecasting tool. In his second lecture Mr. Holmes gave details of the projected operational TIROS system whereby satellites in polar orbits will provide complete global coverage.

Those with the necessary research background must have derived great benefit and inspiration from Professor Suomi's lucid treatment of infra-red and microwave radiometers and their applications. Synoptic meteorologists were however more naturally interested in the lectures of Mr. L. F. Hubert who first dealt with the effectiveness of meteorological satellites in the coverage problem. Then followed "Cloud Picture Interpretation" and "Utilization of Cloud Pictures for Synoptic Analysis."

The television pictures provide a bewildering amount of meteorological information at middle scales, i.e., scales less than synoptic but larger than those visible from a near-earth observation point. Little is known of atmospheric behaviour at these scales and the satellite provides a new mode of observation. Illustrations were given of sub-synoptic scale organization together with interpretations. There are two aspects to the problem of utilizing cloud pictures in synoptic analysis; first, the interpretation of meteorological information from pictures, an identification of scale being of significance and second, the devising of techniques for incorporating the data derived in this way into the analysis.

In a closing lecture Dr. Singer examined the feasibility of utilizing satellites to provide world-wide collection and dissemination of meteorological data. This was a stimulating climax to a most comprehensive series of lectures painstakingly and enthusiastically presented. Confronted with this enthusiasm and obvious achievement, one's initial doubts regarding the future of satellite meteorology seemed somewhat unworthy and ungenerous.

Hitherto, in the United Kingdom (and indeed elsewhere outside of the U.S.A.) satellite information has been available for application in day-to-day forecasting only in the form of "nephanalyses" i.e., facsimile pictures of cloud systems resulting from the interpretation of the original television photographs. These have proved of only limited value for two reasons; first, they were available only for limited areas of the earth's surface, according to the programmed orbits and no continuity was possible; second the nephanalyses were some nine hours old when received. The APT sub-system, first installed in TIROS VIII made possible the local interception of satellite data for orbits passing sufficiently close to the British Isles. With the NIMBUS satellite one more restriction is removed because this satellite maintains a polar orbit and thus affords complete global coverage. We thus have the present capability for picture coverage over a local area surrounding the British Isles, without undue delay, and for subsequent nephanalyses over extensive areas. The layman would expect satellite pictures to improve the daily forecasts and in due course an improvement will undoubtedly be made. For the present, however, the importance of the satellite to forecasting is that it provides a vast amount of data in a new way. The emphasis on cloud and circulation systems must engender new techniques from which we can ultimately look for further advances.

OBITUARY

We regret to announce the death of Mr. J. A. Van Duijnen Montijn, President of the Commission for Maritime Meteorology, at De Bilt on 29 August 1964.

Jan Adriaan Van Duijnen Montijn was born at Oudewater (near Gouda) in January 1899. After training at the Royal Naval College at Den Helder he served from 1921 to 1930 in the Royal Netherlands Navy attaining the rank of Lieutenant Commander. In 1930 he came ashore and was working at the Ministry of Marine at The Hague until 1935. In October 1935 he was appointed an Assistant Director at the Royal Netherlands Meteorological Institute at De Bilt and in January 1956 was promoted to the post of Director of the Division of Oceanography and Marine Meteorology at that Institute.

In August 1960 at the conclusion of the Third Session of the Commission for Maritime Meteorology at Utrecht, Mr. Montijn was elected President of that Commission.

During the 29 years that he was working at De Bilt, his activities included the preparation of oceanographic and meteorological atlases, for which the Netherlands are rightly famous. The preparation and editing of four atlases was mainly his responsibility; 'Sea Areas around Australia' (1949), the 'Red Sea and Gulf of Aden' (1949), the 'Indian Ocean' (1955) and the 'Mediterranean' (1957).

Mr. Montijn had been an active and energetic member of the Commission for Maritime Meteorology since 1952. He showed much energy and enthusiasm as President and was in the midst of the preparations for holding the Fourth Session of that Commission, which is being held at Geneva in December this year, when he died.

Jan Montijn was an efficient and hard worker, a good organizer and was international in his outlook; he was a pleasant companion and had a very good sense of humour. He is survived by a widow and two sons to whom we extend our sympathy.

C.E.N.F.

NOTES AND NEWS

Meteorological Magazine: increase in price

We regret that owing to the need to recover the full cost of postage it will be necessary to increase the price of the *Meteorological Magazine* beginning with the January 1965 issue. The net annual subscription will become £2 including postage, but individual copies will continue to be 3*s.* 0*d.* each.

CORRIGENDUM

Meteorological Magazine, October 1964, p. 290, line 38: after "shallow soil" add "as the trees sway in the wind."

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THE METEOROLOGICAL MAGAZINE

VOL. 93 NO. 1109 DECEMBER 1964

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Printed in England by S. Cockburn & Son Ltd., Ossett, Yorks.
and published by

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Three shillings monthly **Annual subscription 39s. including postage**

S.O. Code No. 40-43-64-12